CHAPTER 3

ELECTRIC FIELD IN MATTER

3.1 INTRODUCTION

The laws of electrostatics that we have formulated in the previous chapters, relate to phenomena where no bulk matter is present. The situation when matter is actually present in an electrostatic field is very different. This chapter concerned with the electric fields in matter includes the following topics:

- Electric current density and continuity equation
- Electric field in conductors and dielectrics
- Electric boundary conditions for different media interfaces
- Capacitors: parallel plate, cylindrical, spherical
- Capacitance and energy stored in capacitors
- Poisson's and Laplace's equations, and their solutions

3.2 ELECTRIC CURRENT DENSITY

Electric current density is defined as the current at a given point through a unit normal area at that point. Current densities are vector quantities and it has the unit of Ampere/m^2. It is represented by J. It can be classified in the following three types:

1. **Convection Current Density:** It is produced by a beam of electrons flowing through an insulating medium. This does not obey Ohm's law. For example, current through a vacuum, liquid and so on is convection current. In general, the convection current density through a filament with charge density ρ_v flowing at a rate $\boldsymbol{u}$ is given as

$$\boldsymbol{J}_c = \rho_v \boldsymbol{u}$$

2. **Conduction Current Density:** It is produced due to flow of electrons in a conductor. This obeys Ohm's law. For example, current in a conductor like copper is conduction current. Conduction current density is defined as

$$\boldsymbol{J} = \sigma \boldsymbol{E}$$

where σ is the conductivity of the conductor, and $\boldsymbol{E}$ is the applied electric field.

3. **Displacement Current Density:** It flows as a result of time-varying electric field in a dielectric material. For example, current through a capacitor when a time-varying voltage is applied is displacement current. It is defined as the rate of change of electric flux density with time, i.e.

$$\boldsymbol{J}_d = \frac{\partial \boldsymbol{D}}{\partial t} = \varepsilon \frac{\partial \boldsymbol{E}}{\partial t}$$

3.3 CONTINUITY EQUATION

Consider a bounded conducting region with volume charge density ρ_v, as shown in Figure 3.1. If the current density through the closed surface S in the conducting region be J, then the continuity equation is defined as

$$\oint_S \boldsymbol{J} \cdot d\boldsymbol{S} = -\frac{d}{dt}\int_v \rho_v dv \qquad \text{(Integral form)}$$

$$\nabla \cdot \boldsymbol{J} = -\frac{d\rho_v}{dt} \qquad \text{(Differential form)}$$

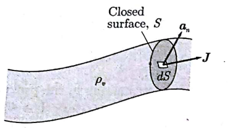

Figure 3.1 : Current through a closed Surface S

3.4 ELECTRIC FIELD IN A DIELECTRIC MATERIAL

When an electric field E is applied to a dielectric material, the electric flux density inside the material is given by

$$\boldsymbol{D} = \varepsilon_0 \boldsymbol{E} + \boldsymbol{P} \qquad \text{...(3.1)}$$

where $\boldsymbol{P}$ is the polarization of the dielectric material.

3.4.1 Electric Susceptibility

Electric susceptibility is a measure of sensitivity of a given dielectric to electric field. Since, polarisation $\boldsymbol{P}$ of a dielectric material varies directly as the applied electric field $\boldsymbol{E}$ so, we can write

$$\boldsymbol{P} \propto \boldsymbol{E}$$

or,
$$\boldsymbol{P} = \chi_e \varepsilon_0 \boldsymbol{E} \qquad \text{...(3.2)}$$

where ε_0 is the permittivity of the free space and χ_e is the electric susceptibility of the material.

3.4.2 Dielectric Constant

In a dielectric material, we define the electric flux density in terms of electric field intensity as

$$\boldsymbol{D} = \varepsilon_0 \varepsilon_r \boldsymbol{E} \qquad \text{...(3.3)}$$

or,
$$\boldsymbol{D} = \varepsilon \boldsymbol{E}$$

where ε is the permittivity of the dielectric material and ε_r is the dielectric constant also called the relative permittivity of the dielectric material.

3.4.3 Relation between Dielectric Constant and Electric Susceptibility

From equations (3.1) and (3.2), we may express the electric flux density as

$$\boldsymbol{D} = \varepsilon_0(1 + \chi_e)\boldsymbol{E}$$

Thus, by comparing the above expression to equation (3.3), we get the relation between dielectric constant and electric susceptibility as

$$\varepsilon_r = 1 + \chi_e$$

3.4.3.1 Dielectric Breakdown

When the applied electric field in a dielectric is sufficiently large, it begins to pull electrons completely out of molecules and the dielectric becomes conducting. When a dielectric becomes conducting, it is said that *dielectric breakdown* has occurred.

3.4.3.2 Dielectric Strength

The dielectric strength of dielectric materials is defined as the maximum electric field which a dielectric can tolerate or withstand without electrical breakdown. Once breakdown occurs, dielectric starts conducting and no longer behaves as dielectric. The dielectric strength is measured in V/m or kV/cm.

3.5 ELECTRIC BOUNDARY CONDITIONS

If an electric field exists in a region consisting of two different media, then the conditions that the field must satisfy at the interface between the two media are called *electric boundary conditions.* To define the electric boundary conditions, we decompose the electrical vector into two orthogonal components as

$$\boldsymbol{E} = \boldsymbol{E}_t + \boldsymbol{E}_n$$

where $\boldsymbol{E}_t$ and $\boldsymbol{E}_n$ are the tangential and normal components of $\boldsymbol{E}$ to the media interface, respectively. Similarly, the electric flux density may be decomposed as

$$\boldsymbol{D} = \boldsymbol{D}_t + \boldsymbol{D}_n$$

where $\boldsymbol{D}_t$ and $\boldsymbol{D}_n$ are the tangential and normal components of $\boldsymbol{D}$ to the media interface, respectively. Following are the electric boundary conditions defined for different media interfaces:

3.5.1 Dielectric–Dielectric Boundary Conditions

Consider the two different dielectric media 1 and 2, characterised by the permittivities ε_1 and ε_2, respectively, shown in Figure 3.2. According to boundary condition, the tangential component of the electric field is continuous at the boundary, i.e.

$$E_{1t} = E_{2t}$$

or
$$\frac{D_{1t}}{\varepsilon_1} = \frac{D_{2t}}{\varepsilon_2}$$

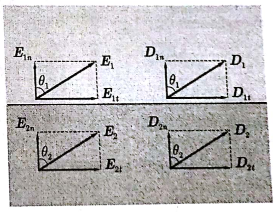

Figure 3.2 : Dielectric-Dielectric Boundary Conditions

If no free charge is present at boundary interface, then the boundary condition for the normal component is given by

$$D_{1n} = D_{2n}$$

or

$$\varepsilon_1 E_{1n} = \varepsilon_2 E_{2n}$$

When the surface charge density at boundary interface is ρ_S, then the boundary condition becomes

$$(D_{1n} - D_{2n}) = \rho_S$$

3.5.2 Conductor-Dielectric Boundary Conditions

For a perfect conductor, the conductivity is infinite, $\sigma \to \infty$, or the resistivity is zero, $\rho \to 0$ and so, the field inside a conductor is zero, (i.e. $E = 0$). Assume that medium 1 is a dielectric with permittivity ε, and medium 2 is a conductor. Let E_t and E_n respectively be the tangential and normal components of the electric field intensity in the dielectric at boundary interface. So, we define the boundary condition for tangential components as

$$E_t = 0$$

or,

$$D_t = 0$$

Also, the boundary condition for normal component is defined as

$$D_n = \rho_S$$

or,

$$E_n = \frac{D_n}{\varepsilon} = \frac{\rho_S}{\varepsilon}$$

3.5.3 Conductor-Free Space Boundary Conditions

These boundary conditions will be identical as those for a conductor-dielectric boundary except that ε will be replaced by ε_0, so that the boundary conditions for the tangential and normal components become

$$D_t = 0 = E_t\ ,$$

$$D_n = \rho_S\ ,$$

and

$$E_n = \frac{\rho_S}{\varepsilon_0}$$

3.6 CAPACITOR

A capacitor essentially consists of two conducting surfaces separated by a layer of insulating medium called Dielectric. The purpose of capacitor is to store the energy in Electrostatic Field. Figure 3.3 shows the capacitor with three different shapes.

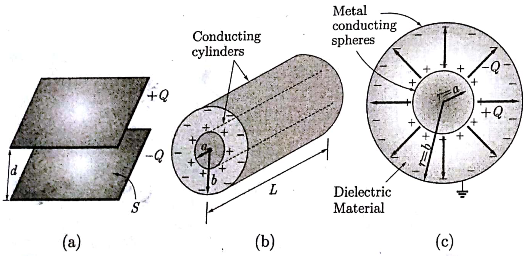

Figure 3.3: (a) Parallel Plate Capacitor, (b) Cylindrical Capacitor, (c) Spherical Capacitor

3.6.1 Capacitance

The property of capacitor to store the electricity is called its capacitance. Suppose, we give Q coulombs of charge to one of the two plates of capacitor and if a potential difference of V volts is established between the two, then its capacitance is defined as

$$C = \frac{Q}{V} = \frac{\text{Charge}}{\text{Potential Difference}}$$

The unit of capacitance is coulomb/volt which is also called Farad.

Capacitance of a Parallel plate Capacitor

Consider the two metallic plates of equal area S separated by a distance d. If ε be the permittivity of the dielectric medium between the parallel plates, then the capacitance of the parallel plate capacitor is given by

$$C = \frac{\varepsilon S}{d}$$

Capacitance of a Cylindrical Capacitor

Consider a cylindrical capacitor of length L, inner radius a, and outer radius b. If ε be the permittivity of the dielectric medium between the cylinders, then the capacitance of the cylindrical capacitor is given by

$$C = \frac{2\pi\varepsilon L}{\ln(b/a)}$$

Capacitance of a Spherical Capacitor

Consider a spherical capacitor with inner and outer radii, a and b respectively. If ε be the permittivity of the dielectric medium between the spheres, then the capacitance of the spherical capacitor is given by

$$C = 4\pi\varepsilon\left(\frac{ab}{b-a}\right)$$

3.6.2 Energy Stored in a Capacitor

The energy stored in a capacitor is equal to the work done to charge it. In general, the stored energy in a capacitor is defined as

$$W_{\text{stored}} = \frac{1}{2}CV^2$$

where W_{stored} is the energy in Joule, C is the capacitance in Farad, and V is the voltage in Volt.

3.7 POISSON'S AND LAPLACE'S EQUATION

Consider a certain region with the volume charge density ρ_v and permittivity ε. In this region, Poisson's equation is defined as

$$\nabla^2 V = -\frac{\rho_v}{\varepsilon}$$

where V is the electric potential in the region. In the special case of a charge-free region (i.e. $\rho_v = 0$), Poisson's equation reduces to

$$\nabla^2 V = 0$$

which is known as Laplace's equation.

3.7.1 Uniqueness Theorem

According to uniqueness theorem, if a solution to Laplace's equation or Poisson's equation can be found that satisfies the boundary conditions, then the solution is unique.

METHODOLOGY: TO SOLVE POISSON'S AND LAPLACE'S EQUATION

Following are the steps involved for solving a boundary value problem, using Poisson's or Laplace's equation :

Step 1: The equation is solved using either

(i) direct integration when V is a function of one variable.

(ii) separation of variables if V is a function of more than one variable.

Step 2: The unknown integration constants are found by applying the boundary conditions, so that the solution becomes unique.

Step 3: Having obtained V, the field is obtained from the relation,

$$\boldsymbol{E} = -\nabla V$$

Step 4: The surface charge density at the boundary surface is given by

$$\rho_S = D_n = \varepsilon E_n$$

where E_n is the normal component of the field.

Step 5: The charge induced on a conductor is obtained from the relation

$$Q = \int_S \rho_S \, dS$$

Step 6: The capacitance between two conductors is obtained from the relation

$$C = \frac{Q}{V}$$

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EXERCISE 3.1

Common Data For Q. 1 and 2:

In a certain region current density is given by

$$\boldsymbol{J} = \frac{40}{\rho}\boldsymbol{a}_\rho - \frac{20\sin\phi}{(\rho^2+1)}\boldsymbol{a}_z \text{ A/m}^2$$

MCQ 3.1.1 Total current crossing the plane $z = 2$ in the $\boldsymbol{a}_z$ direction for $\rho < 4$ will be

(A) 0 A (B) 1.5 mA
(C) −32 A (D) 20 A

MCQ 3.1.2 Volume charge density in the region at a particular point (ρ_0, ϕ_0, z_0) will be

(A) non uniform (B) linearly increasing with time
(C) linearly decreasing with time (D) constant with respect to time

Common Data For Q. 3 to 6 :

In a cylindrical system, two perfectly conducting surfaces of length 2 m are located at $\rho = 3$ and $\rho = 5$ cm. The total current passing radially outward through the medium between the cylinders is 6 A.

MCQ 3.1.3 If a conducting material having conductivity $\sigma = 0.05$ S/m is present for $3 < r \leq 5$ cm then the electric field intensity at $\rho = 4$ cm will be

(A) $238.7\boldsymbol{a}_\rho$ V/m (B) $150\boldsymbol{a}_\rho$ V/m
(C) $318.3\boldsymbol{a}_\rho$ V/m (D) 0 V/m

MCQ 3.1.4 The voltage between the cylindrical surfaces will be

(A) 4.88 volt (B) 1.45 volt
(C) 2.32 volt (D) 3 volt

MCQ 3.1.5 The resistance between the cylindrical surfaces will be

(A) 0.813 Ω (B) 2.44 Ω
(C) 0.5 Ω (D) 8.13 Ω

MCQ 3.1.6 The total dissipated power in the conducting material will be

(A) 175.7 W (B) 18 W
(C) 29.3 W (D) 0.8 W

MCQ 3.1.7 A solid wire of radius r and conductivity σ_1 has a jacket of material having conductivity σ_2. If the inner and outer radius of the jacket are r and R respectively then the ratio of the current densities in the two materials will

(A) depend on r only (B) depend on R only
(C) depend on both r and R (D) independent of both r and R

Common Data For Q. 8 to 10 :

The potential field in a slab of a dielectric material that has the relative permittivity $\varepsilon_r = 8/5$ is given by $V = -500y$.

MCQ 3.1.8 Electric field intensity in the material will be

(A) $50\boldsymbol{a}_y$ V/m (B) $500\boldsymbol{a}_y$ V/m
(C) $-500\boldsymbol{a}_y$ V/m (D) 0

MCQ 3.1.9 The electric flux density inside the material will be

(A) $4.43\,\text{nC/m}^2$ (B) $3.54\boldsymbol{a}_y\,\mu\text{C/m}^2$
(C) $8.85\,\text{nC/m}^2$ (D) $7.08\boldsymbol{a}_y\,\text{nC/m}^2$

MCQ 3.1.10 Polarization of the material will be

(A) $2.66\boldsymbol{a}_y\,\text{nC/m}^2$ (B) $7.08\,\text{nC/m}^2$
(C) $5.31 \times 10^{-12}\boldsymbol{a}_y\,\text{C/m}^2$ (D) $3\boldsymbol{a}_y\,\text{C/m}^2$

Common Data For Q. 11 and 12:

Two perfect dielectrics with dielectric constant $\varepsilon_{r1} = 2$ and $\varepsilon_{r2} = 5$ are defined in the region 1 ($y \geq 0$) and region 2 ($y < 0$) respectively. Consider the electric field intensity in the 1st region is given by

$$\boldsymbol{E}_1 = 50\boldsymbol{a}_x + 20\boldsymbol{a}_y - 10\boldsymbol{a}_z\ \text{kV/m}$$

MCQ 3.1.11 The Flux charge density in the 2nd region will be

(A) $2.21\boldsymbol{a}_x + 0.35\boldsymbol{a}_y - 0.44\boldsymbol{a}_z\,\mu\text{C/m}^2$
(B) $2.21\boldsymbol{a}_x + 0.35\boldsymbol{a}_y - 0.44\boldsymbol{a}_z\,\text{nC/m}^2$
(C) $2.21\boldsymbol{a}_x + 0.88\boldsymbol{a}_y - 0.44\boldsymbol{a}_z\,\text{nC/m}^2$
(D) $0.4\boldsymbol{a}_x + 0.07\boldsymbol{a}_y - 0.08\boldsymbol{a}_z\,\text{nC/m}^2$

MCQ 3.1.12 The energy density in the 2nd region will be

(A) $66.37\,\text{mJ/m}^3$ (B) $118\,\text{mJ/m}^3$
(C) $472 \times 10^6\,\text{J/m}^3$ (D) $59\,\text{mJ/m}^3$

MCQ 3.1.13 An infinite plane dielectric slab of thickness d and having permittivity $\varepsilon = 4\varepsilon_0$ occupies the region $0 < z < d$. If a uniform electric field $\boldsymbol{E} = E_0\boldsymbol{a}_z$ is applied in the free space then the electric flux density($\boldsymbol{D}_{in}$) and electric field intensity($\boldsymbol{E}_{in}$) inside the dielectric slab will be respectively

(A) $\frac{E_0}{4}\boldsymbol{a}_z$ and $\varepsilon_0 E_0\boldsymbol{a}_z$ (B) $\varepsilon_0 E_0\boldsymbol{a}_z$ and $\frac{E_0}{4}\boldsymbol{a}_z$
(C) $4E_0\boldsymbol{a}_z$ and $\frac{E_0}{4}\boldsymbol{a}_z$ (D) $\varepsilon_0 E_0\boldsymbol{a}_z$ and $4E_0\boldsymbol{a}_z$

MCQ 3.1.14 The energy stored in an electric field made up of two fields $\boldsymbol{E}_1$ and $\boldsymbol{E}_2$ is W_{net} where as the energies stored in individual fields $\boldsymbol{E}_1$ and $\boldsymbol{E}_2$ are W_1 and W_2 respectively so the correct relation between the energies is

(A) $W = W_1 + W_2$ (B) $W = \sqrt{W_1 W_2}$
(C) $W > W_1 + W_2$ (D) $W < W_1 + W_2$

MCQ 3.1.15 When a neutral dielectric is being polarized in an electric field then the total bound charge of the dielectric will be

(A) zero (B) positive
(C) negative (D) depends on nature of dielectric

MCQ 3.1.16 A cylindrical wire of length l and cross sectional radius r is formed of a material with conductivity $10^6\,(\Omega\text{m})^{-1}$. If the total conductance of the wire is $10^6\,(\Omega)^{-1}$ then the correct relation between l and r is

(A) $r = \sqrt{\frac{\pi}{l}}$ (B) $r = \sqrt{\frac{l}{\pi}}$
(C) $2\pi r = l$ (D) $r = l$

MCQ 3.1.17 Medium between the two conducting parallel sheets of a capacitor has the permittivity ε and conductivity σ. The time constant of the capacitor will be

(A) $\frac{\varepsilon}{\sigma}$ (B) $\frac{\sigma}{\varepsilon}$
(C) $\sigma\varepsilon$ (D) $1/\sigma\varepsilon$

Common Data For Q. 18 to 20 :

In spherical coordinate system, the current density in a certain region is given by

$$\mathbf{J} = \frac{1}{r}e^{-10^3 t}\boldsymbol{a}_r\ \text{A/m}^2$$

MCQ 3.1.18 At $t = 1$ ms, how much current is crossing the surface $r = 6$?

(A) 75.03 A (B) 27.7 A
(C) 0.37 A (D) 2.77 A

MCQ 3.1.19 At a particular time t, the charge density $\rho_v(r, t)$ at any point in the region is directly proportional to. (Assume $\rho_v \to 0$ as $t \to \infty$)

(A) r (B) $\frac{1}{r}$
(C) $\frac{1}{r^2}$ (D) r^2

MCQ 3.1.20 The velocity of charge density at $r = 0.6$ m will be

(A) $6\boldsymbol{a}_r$ m/s
(B) $1000\boldsymbol{a}_r$ m/s
(C) $0.6 \times 10^{-3}\boldsymbol{a}_r$ m/s
(D) $600\boldsymbol{a}_r$ m/s

Common Data For Q. 21 and 22 :

Two uniform infinite line charges of 5 pC/m each are located at $x = 0$, $y = 1$ and $x = 0$, $y = 2$ respectively. Consider the surface $y = 0$ is a perfect conductor that has the zero potential.

MCQ 3.1.21 Electric potential at point $P(-1, -2, 0)$ will be

(A) 1.2 volt (B) −0.2 volt
(C) +0.2 volt (D) −0.04 volt

MCQ 3.1.22 Electric field at the point P will be

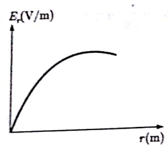
(A) $0.12\boldsymbol{a}_x - 0.003\boldsymbol{a}_y$ V/m
(B) $0.12\boldsymbol{a}_x - 0.086\boldsymbol{a}_y$ V/m
(C) $723\boldsymbol{a}_x - 18.9\boldsymbol{a}_y$ V/m
(D) $0.024\boldsymbol{a}_x - 0.086\boldsymbol{a}_y$ V/m

Common Data For Q. 23 and 24 :

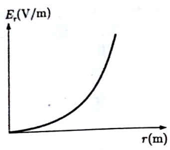
A sphere carries a polarization $P(r) = 2r a_r$ where r is the distance from the center of the sphere.

MCQ 3.1.23 Consider E_r is the electric field component in the radial direction inside the sphere. The plot of E_r with respect to r will be

(A)



(B)



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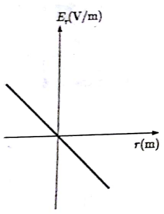

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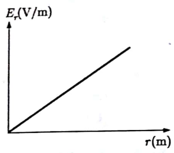
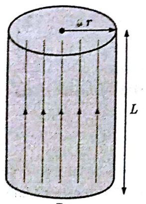


MCQ 3.1.24 If the radius of the sphere is a then the electric field outside the sphere will be

(A) $-4\pi a^3$ (B) $8\pi a^3$
(C) 0 (D) $-8\pi a^3$

Common Data For Q. 25 to 27 :

A short cylinder of radius r and length L carries a uniform polarization P, parallel to its axis as shown in the figure.



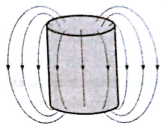
P
(Uniform)

MCQ 3.1.25 Total bound charge by the cylinder will be

(A) $2P$ coulomb (B) P coulomb
(C) 0 coulomb (D) $-P$ coulomb

MCQ 3.1.26 If $L = 2r$ then the electric field lines of the cylinder will be as

(A)



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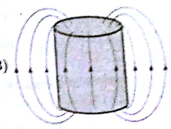

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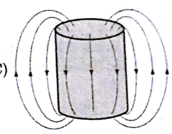

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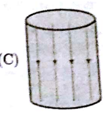
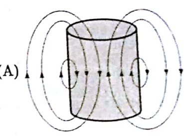


9 **MCQ 3.1.27** The lines of flux charge density will be as

(A)



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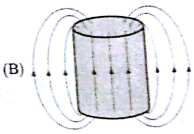
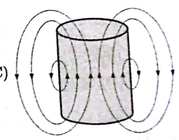
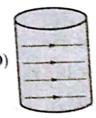


(C)



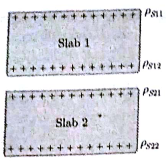
(D)



MCQ 3.1.28 An infinite plane conducting slab carries uniformly distributed surface charges on both of it's surface. If the sum of the charge densities on the two surfaces is ρ_{so} C/m^2 then the surface charge densities on the two surfaces will be

(A) $\rho_{so}/2$, $\rho_{so}/2$ (B) $2\rho_{so}$, $-\rho_{so}$
(C) 0, ρ_{so} (D) None of these

MCQ 3.1.29 Two infinite plane parallel conducting slabs carry uniformly distributed surface charges ρ_{S11}, ρ_{S12}, ρ_{S21} and ρ_{S22} on all the four surfaces as shown in the figure.



Which of the following gives the correct relation between the charge densities ?

(A) $\rho_{s11} = \rho_{s22}$, $\rho_{s12} = \rho_{s21}$

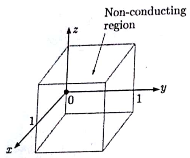
(B) $\rho_{s11} = \rho_{s22}$, $\rho_{s12} = -\rho_{s21}$

(C) $\rho_{s11} = \rho_{s12}$, $\rho_{s21} = \rho_{s22}$

(D) $\rho_{s11} = -\rho_{s22}$, $\rho_{s12} = -\rho_{s21}$

Common Data For Q. 30 and 31 :

The plane surfaces $x = 0$, $x = 1$, $y = 0$ and $y = 1$ form the boundaries of conductors extending away from the region between them as shown below.



If the electrostatic potential in the region between the surfaces is given by $5xy$ volts then the surface charge density on the surface ;

MCQ 3.1.30 $x = 0$ is

(A) $-5\varepsilon_0 y$

(B) $-5\varepsilon_0 x$

(C) $-5\varepsilon_0(x + y)$

(D) $5\varepsilon_0(xy)$

MCQ 3.1.31 $y = 0$ is

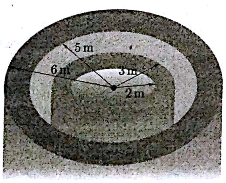
(A) $-5\varepsilon_0 y$

(B) $-5\varepsilon_0 x$

(C) $-5\varepsilon_0(x + y)$

(D) $5\varepsilon_0 xy$

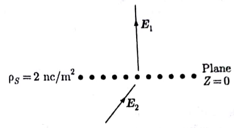
MCQ 3.1.32 Two infinitely long coaxial, hollow cylindrical conductors of inner radii 2 m and 5 m respectively and outer radii 3 m and 6 m, respectively as shown in the figure, carry uniformly distributed surface charges on all four of their surfaces.



If net surface charge per unit length is 10 C/m and 6 C/m for the inner and outer conductor respectively then the surface charge densities on the four surface will be

Surface →	$\rho = 2$ m	$\rho = 3$ m	$\rho = 5$ m	$\rho = 6$ m
(A)	0	$5/3\pi$	$-1/\pi$	$4/3\pi$
(B)	$5/3\pi$	$-1/\pi$	0	$4/3\pi$
(C)	$1/\pi$	$-1/\pi$	$2/\pi$	$-2/\pi$
(D)	0	$-1/\pi$	$1/\pi$	0

MCQ 3.1.33 Plane $z = 0$ defines a surface charge layer with the charge density $\rho_S = 2n$ C/m^2 as shown in figure. If the electric field intensity in the region $z < 0$ is $\boldsymbol{E}_2 = 2\boldsymbol{a}_x + 3\boldsymbol{a}_y - 2\boldsymbol{a}_z$ V/m then the field intensity $\boldsymbol{E}_1$ in the region $z > 0$ will be



(A) $220\boldsymbol{a}_x + 219\boldsymbol{a}_y - 2\boldsymbol{a}_z$

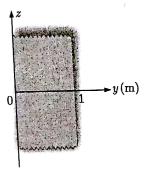
(B) $2\boldsymbol{a}_x + 3\boldsymbol{a}_y + 224\boldsymbol{a}_z$

(C) $222\boldsymbol{a}_x + 221\boldsymbol{a}_y + 2\boldsymbol{a}_z$

(D) $2\boldsymbol{a}_x + 3\boldsymbol{a}_y + 226\boldsymbol{a}_z$

Common Data For Q. 34 and 35 :

An infinite plane dielectric slab of 1 m thickness is placed in free space such that it occupies the region $0 < y < 1$ m as shown in the figure.



Dielectric slab has the non uniform permittivity defined as

$$\varepsilon = \frac{4\varepsilon_0}{(1+y)^2} \quad \text{for } 0 < y < 1$$

9 **MCQ 3.1.34** If a uniform electric field $\boldsymbol{E} = 4\boldsymbol{a}_y$ V/m is applied in free space then bound surface charge densities on the surface $y = 0$ and $y = 1$ will be

	at $y = 0$	at $y = 1$
(A)	0	$-3\varepsilon_0$
(B)	$-3\varepsilon_0$	0
(C)	$3\varepsilon_0$	0
(D)	$-5\varepsilon_0$	$8\varepsilon_0$

MCQ 3.1.35 As we move from the surface $y=0$ toward the surface $y=1$ inside the dielectric slab, polarization volume charge density will be
(A) linearly increasing
(B) linearly decreasing
(C) Constant
(D) zero at all points

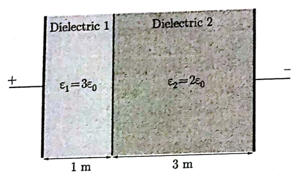
MCQ 3.1.36 In a spherical coordinate system the region $a<r<b$ is occupied by a dielectric material. A point charge Q is situated at the origin. It is found that the electric field intensity inside the dielectric is given by

$$\boldsymbol{E} = \frac{Q}{4\pi\varepsilon_0 b^2}\boldsymbol{a}_r \qquad \text{for } a<r<b$$

The relative permittivity of the dielectric will be
(A) (b^2/r^2)
(B) (a^2/r^2)
(C) (r^2/a^2)
(D) (a^2/b^2)

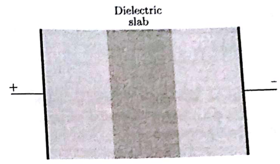
MCQ 3.1.37 Two perfectly conducting, infinite plane parallel sheets separated by a distance d carry uniformly distributed surface charges of equal and opposite densities ρ_{S0} and $-\rho_{S0}$ respectively. The medium between the sheets is filled by a dielectric of non uniform permittivity which varies linearly from a value of ε_1 near one plate to value of ε_2 near the second plate. The potential difference between the two sheets will be
(A) $\frac{\rho_{S0}d}{\varepsilon_2-\varepsilon_1}$
(B) $\frac{\rho_{S0}}{d(\varepsilon_2-\varepsilon_1)}\ln\left(\frac{\varepsilon_2}{\varepsilon_1}\right)$
(C) $\frac{\rho_{S0}d}{\varepsilon_2-\varepsilon_1}\ln\left(\frac{\varepsilon_2}{\varepsilon_1}\right)$
(D) $\rho_{S0}\ln\left(\frac{\varepsilon_2}{\varepsilon_1}\right)$

MCQ 3.1.38 A parallel plate capacitor has two layers of dielectrics with permittivities $\varepsilon_1=3\varepsilon_0$ and $\varepsilon_2=2\varepsilon_0$ as shown in the figure.



If the total voltage drop in the capacitor is 9 Volt then the voltage drop in 1st and 2nd dielectric region will be respectively
(A) $\frac{18}{11}$ Volt, $\frac{81}{11}$ Volt
(B) 3 Volt, 6 Volt
(C) $\frac{81}{11}$ Volt, $\frac{18}{11}$ Volt
(D) 6 Volt, 3 Volt

MCQ 3.1.39 A dielectric slab is inserted in the medium between two plates of a capacitor as shown in the figure



The capacitance across the capacitor will remain constant
(A) if the slab is moved rightward or leftward
(B) if the slab is pulled outward of the capacitor
(C) (A) and (B) both
(D) none of these

MCQ 3.1.40 A potential field in free space is given as $V=40\cos\theta\sin\frac{\phi}{r}$ V Point $P(r=2,\theta=\pi/3,\phi=\pi/2)$ lies on a conducting surface. The equation of the conducting surface is
(A) $32\cos\theta\sin\phi=r^3$
(B) $16\cos\phi\sin\theta=r^3$
(C) $16\cos\theta\sin\phi=r^3$
(D) $32\cos\phi\sin\theta=r^3$

****

EXERCISE 3.2

QUES 3.2.1 A certain current density at any point (ρ, ϕ, z) in cylindrical coordinates is given by $\boldsymbol{J} = 10e^z(\rho^2\mathbf{a}_\rho + \mathbf{a}_z)\,\text{A/m}^2$. The total current passing the plane $z = 0$, $0 \le \rho \le 2$ in the $\boldsymbol{a}_z$ direction is ____ Ampere.

QUES 3.2.2 Given the current density in a certain region $\boldsymbol{J} = r\cos^2\theta\mathbf{a}_r + r^2\sin\theta\mathbf{a}_\theta - r^2\mathbf{a}_\phi\,\text{A/m}^2$. The total current crossing the surface defined by $\theta = 90°$, $0 < \phi < 2\pi$, $0 < r < 1\,\text{m}$ is ____ Ampere.

QUES 3.2.3 The current density in a cylindrical wire of radius 16 mm placed along the z-axis is $\boldsymbol{J} = \frac{50}{\rho}\boldsymbol{a}_z\,\text{A/m}^2$. What will be the total current (in Ampere) flowing through the wire ?

Common Data For Q. 4 and 5 :

Atomic hydrogen contains $5.5 \times 10^{19}\,\text{atom/cm}^3$ at a certain temperature and pressure. If an electric field of $40\,\text{kV/m}$ is applied, each dipole formed by the electron and positive nucleus has an effective length of $7.1 \times 10^{-16}\,\text{m}$.

QUES 3.2.4 The polarization due to the induced dipole will be ____ nC/m^2.

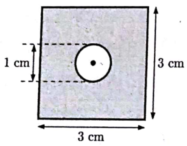
QUES 3.2.5 What will be the dielectric constant of the atomic hydrogen ?

QUES 3.2.6 The dielectric constant of the material in which the electric flux density is double of the polarization is ____

QUES 3.2.7 An electric dipole is being placed in an electric field intensity $1.5\boldsymbol{a}_z - \boldsymbol{a}_z\,\text{V/m}$ If the moment of the dipole be $\boldsymbol{p} = -2\boldsymbol{a}_z + 3\boldsymbol{a}_y\,\text{C-m}$ then energy of the dipole will be ____ Joule.

Common Data For Q. 8 and 9 :

A lead bar of square cross section has a hole of radius 0.5 cm bored along its length as shown in the figure.



(Conductivity of lead $= 5 \times 10^6 (\Omega\text{m})^{-1}$)

QUES 3.2.8 If the length of the lead bar is 8 m then the resistance between the square ends of the bar will be ____ mΩ.

QUES 3.2.9 If the hole in the lead bar is completely filled with copper, what will be the resistance (in $\mu\Omega$) of the composite bar ?

(Resistivity of copper $= 1.72 \times 10^{-8}\,\Omega\text{m}$)

Common Data For Q. 10 and 11 :

A capacitor is formed by two concentric conducting spherical shells of radii $a = 1\,\text{cm}$ and $b = 2\,\text{cm}$ centered at origin. Interior of the spherical capacitor is a perfect dielectric with $\varepsilon_r = 4$.

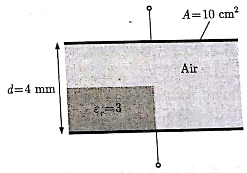
QUES 3.2.10 What is the capacitance (in pF) of the capacitor ?

QUES 3.2.11 If a portion of dielectric is removed from the capacitor such that $\varepsilon_r = 1$ for $\frac{\pi}{2} < \phi < \pi$ and $\varepsilon_r = 4$ for the rest of the portion, then the capacitance of the composite capacitor will be ____ pF.

QUES 3.2.12 Two conducting surfaces are present at $x = 0$ and $x = 5\,\text{mm}$ and the space between them are filled by dielectrics such that $\varepsilon_{r1} = 2.5$ for $0 < x < 1\,\text{mm}$ and $\varepsilon_{r2} = 4$ for $1 < x < 3\,\text{mm}$ rest of the region is air filled. The capacitance per square meter of surface area will be ____ nF/m^2.

QUES 3.2.13 Two coaxial conducting cylinders of radius 4 cm and 8 cm is lying along z-axis. The region between the cylinders contains a layer of dielectric from $\rho = 4\,\text{cm}$ to $\rho = 6\,\text{cm}$ with $\varepsilon_r = 4$. If the length of cylinders is 1 m then the capacitance of the configuration will be ____ pF.

QUES 3.2.14 A parallel plate capacitor is quarter filled with a dielectric ($\varepsilon_r = 3$) as shown in the figure. The capacitance of the capacitor will be ____ pF.

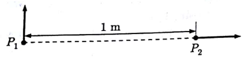


QUES 3.2.15 A thin rod of certain cross sectional area extends along the y-axis from $y = 0\,\text{m}$ to $y = 5\,\text{m}$. If the polarization of the rod is along it's length and is given by $P_y = 2y^2 + 3$, what will be the total bound charge of the rod ?

QUES 3.2.16 A neutral atom of polarizability α is situated at a distance 1 m from a point charge $\frac{1}{9}$ nC. If the force of attraction between them is F, then $\frac{F}{\alpha} =$ ____ N

Common Data For Q. 17 and 18 :

The two dipoles P_1, P_2 with dipole moment 2 nC-m and 9 nC-m respectively are placed at 1 m distance apart as shown in figure.



QUES 3.2.17 The torque on P_2 due to P_1 will be ____ μN − m.

QUES 3.2.18 The torque on P_1 due to P_2 will be ____ μN − m.

Common Data For Q. 19 to 21 :

A thick spherical shell is made of dielectric material with a polarization

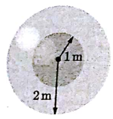
$$P(r) = \frac{5}{r}a_r \text{ nC/m}^2 \text{ where } r \text{ is the distance from its centre.}$$

QUES 3.2.19 If the spherical shell is centred at origin and has the inner radius 2 m and outer radius 6 m then the electric field intensity at $r = 1$ m will be ____ V/m.

QUES 3.2.20 What will be the electric field at $r = 7$ m ?

QUES 3.2.21 If at $r = 5$ m, the electric field intensity is $E = \frac{ka_r}{\varepsilon_0}$ then value of k is ____.

QUES 3.2.22 A spherical conductor of radius 1 m carries a charge 3 mC. It is surrounded, out to radius 2 m, by a linear dielectric material of dielectric constant $\varepsilon_r = 3$, as shown in the figure. What will be the energy (in Joule) of this configuration ?



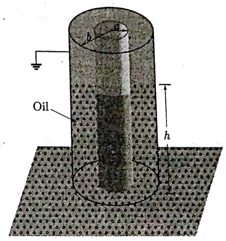
QUES 3.2.23 A sphere of radius $1/\sqrt{\pi}$ m is made of dielectric material with dielectric constant $\varepsilon_r = 2$. If a uniform free charge density 0.6 nC/m³ is embedded in it then the potential at the centre of the sphere will be ____ Volt.

QUES 3.2.24 A parallel plate capacitor is filled with a non uniform dielectric characterized by $\varepsilon_r = 2(1 + 100a^2)$ where a is the distance from one plate in meter. If the surface area of the plates is 0.2 m² and separation between them is 10 cm then the capacitance of the capacitor will be ____ pF.

QUES 3.2.25 A two wire transmission line consists of two perfectly conducting cylinders, each having a radius of 0.2 cm, separated by a centre to centre distance of 2 cm. The medium surrounding the wires has relative permittivity $\varepsilon_r = 2$. If a 100 V source is connected between the wires then the stored charge per unit length on each wire will be ____ nC/m.

QUES 3.2.26 A tank is filled with dielectric oil of susceptibility $\chi_e = 1$. Two long coaxial cylindrical metal tubes of radii 1 mm and 3 mm stand vertically in the tank as shown in the figure. The outer tube is grounded and inner one is maintained at 2 kV potential. To what height (in μm) does the oil rise in the space between the tubes ?

(mass density of oil = 0.01 gm/cm³)



QUES 3.2.27 A conducting spherical shell of inner radii 2 m and outer radii 3 m carry uniformly distributed surface charge on it's inner and outer surfaces. If the net surface charge is 9 C for the conducting spherical shell then, the surface charge density on outer surface will be ____ C/m².

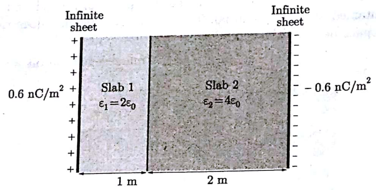
QUES 3.2.28 An infinite plane dielectric slab with relative permittivity $\varepsilon_r = 5$ occupies the region $x > 0$. If a uniform electric field $E = 10a_x$ V/m is applied in the region $x < 0$ (free space) then the polarization inside the dielectric will be $k\varepsilon_0 a_x$ C/m² such that value of k is ____

QUES 3.2.29 Two perfectly conducting, infinite plane parallel sheets separated by a distance 2 m carry uniformly distributed surface charges of equal and opposite densities +5 nC/m² and −5 nC/m² respectively. If the medium between two plates is a dielectric of uniform permittivity $\varepsilon = 4\varepsilon_0$ then the potential difference between the two plates will be ____ kV.

QUES 3.2.30 Two perfectly conducting, infinite plane parallel sheet separated by a distance 0.5 cm carry uniformly distributed surface charges of equal and opposite densities. If the potential difference between the two plates is 5 kV and the medium between the plates is free space, what will be the charge densities (in μC) on the plates ?

QUES 3.2.31 A steel wire has a radius of 2 mm and a conductivity of 2×10^6 S/m. The steel wire has an aluminium ($\sigma = 3.8 \times 10^7$ S/m) coating of 2 mm thickness. The total current carried by this hybrid conductor be 80 A. The current density in steel J_{st} is ____ $\times 10^5$ A/m^2.

QUES 3.2.32 The medium between two perfectly conducting infinite plane parallel sheets consists of two dielectric slabs of thickness 1 m and 2 m having permittivities $\varepsilon_1 = 2\varepsilon_0$ and $\varepsilon_2 = 4\varepsilon_0$ respectively as shown in the figure.



If the conducting sheets carry uniformly distributed surface charges of equal and opposite densities $0.6\,\text{nC/m}^2$ and $-0.6\,\text{nC/m}^2$ respectively, what will be the potential difference (in Volt) between the sheets ?

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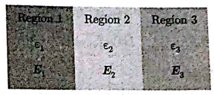
EXERCISE 3.3

MCQ 3.3.1 The electric field in the three regions as shown in the figure are respectively $\mathbf{E}_1$, $\mathbf{E}_2$ and $\mathbf{E}_3$ and all the boundary surfaces are charge free.



If $\varepsilon_1 = \varepsilon_3 \neq \varepsilon_2$, then the correct relation between the electric field is

(A) $\mathbf{E}_1 \neq \mathbf{E}_2 \neq \mathbf{E}_3$ (B) $\mathbf{E}_1 = \mathbf{E}_3 \neq \mathbf{E}_2$
(C) $\mathbf{E}_1 = \mathbf{E}_2 = \mathbf{E}_3$ (D) $\mathbf{E}_1 = \mathbf{E}_2 \neq \mathbf{E}_3$

MCQ 3.3.2 The unit of polarization in dielectric is

(A) C/m^2 (B) C/m
(C) C/m^3 (D) C-m^2

MCQ 3.3.3 The Laplacian operator, ∇^2

(A) has unit of m^2 (B) is a vector operator
(C) has unit of 1/m^2 (D) has no unit

MCQ 3.3.4 Laplace's equation has

(A) two solutions (B) infinite solutions
(C) no solution (D) only one solution

MCQ 3.3.5 The surface charge density in a good dielectric is

(A) zero (B) ρ_s
(C) infinity (D) $-\rho_s$

MCQ 3.3.6 If $\varepsilon_r = 2$ for a dielectric medium, its electric susceptibility is

(A) 1 (B) 2
(C) 3 (D) $2\varepsilon_0$

MCQ 3.3.7 Example of non-polar type of dielectric is

(A) water (B) hydrochloric acid
(C) sulphur dioxide (D) oxygen

MCQ 3.3.8 Example of polar type of dielectric is

(A) oxygen (B) water
(C) hydrogen (D) nitrogen

MCQ 3.3.9 If the voltage applied across a capacitor is increased, the capacitance value

(A) increases (B) decreases
(C) remains constant (D) becomes infinity

MCQ 3.3.10 If electric susceptibility of a dielectric is 4, its relative permittivity is
(A) 5 (B) 4
(C) 3 (D) 2

MCQ 3.3.11 Poisson's equation is
(A) $\nabla^2 V = \rho_v / \varepsilon$ (B) $\nabla^2 V = -\rho_v / \varepsilon$
(C) $\nabla^2 V = -\rho_v$ (D) $\nabla^2 V = -\rho_v / \varepsilon$

MCQ 3.3.12 Boundary condition for the normal component of $\boldsymbol{E}$ on the boundary of a dielectric is
(A) $E_{n1} = E_{n2}$ (B) $E_{n1} - E_{n2} = \rho_s$
(C) $E_{n1} = \frac{\varepsilon_2}{\varepsilon_1} E_{n2}$ (D) $E_{n1} = 0$

MCQ 3.3.13 The boundary condition on $\boldsymbol{E}$ is
(A) $\boldsymbol{a}_n \times (\boldsymbol{E}_1 - \boldsymbol{E}_2) = 0$ (B) $\boldsymbol{a}_n \cdot (\boldsymbol{E}_1 - \boldsymbol{E}_2) = 0$
(C) $\boldsymbol{E}_1 = \boldsymbol{E}_2$ (D) none of these

MCQ 3.3.14 The electric field just above a conductor is always
(A) normal to the surface (B) tangential to source
(C) zero (D) ∞

MCQ 3.3.15 The normal components of $\boldsymbol{D}$ are
(A) continuous across a dielectric boundary
(B) discontinuous across a dielectric boundary
(C) zero
(D) ∞

****

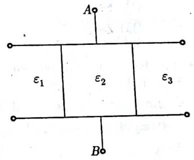
EXERCISE 3.4

MCQ 3.4.1 A parallel plate air-filled capacitor has plate area of $10^{-4}\,\mathrm{m}^2$ and plate separation of 10^{-3} m. It is connected to a 0.5 V, 3.6 GHz source. The magnitude of the displacement current is ($\varepsilon = \frac{1}{36\pi} 10^{-9}$ F/m)
(A) 10 mA (B) 100 mA
(C) 10 A (D) 1.59 mA

MCQ 3.4.2 Medium 1 has the electrical permittivity $\varepsilon_1 = 1.5\varepsilon_0$ farad/m and occupies the region to the left of $x = 0$ plane. Medium 2 has the electrical permittivity $\varepsilon_2 = 2.5\varepsilon_0$ farad/m and occupies the region to the right of $x = 0$ plane. If $\boldsymbol{E}_1$ in medium 1 is $\boldsymbol{E}_1 = (2\boldsymbol{a}_x - 3\boldsymbol{a}_y + 1\boldsymbol{a}_z)$ volt/m, then $\boldsymbol{E}_2$ in medium 2 is
(A) $(2.0\boldsymbol{a}_x - 7.5\boldsymbol{a}_y + 2.5\boldsymbol{a}_z)$ volt/m
(B) $(2.0\boldsymbol{a}_x - 2.0\boldsymbol{a}_y + 0.6\boldsymbol{a}_z)$ volt/m
(C) $(2.0\boldsymbol{a}_x - 3.0\boldsymbol{a}_y + 1.0\boldsymbol{a}_z)$ volt/m
(D) $(2.0\boldsymbol{a}_x - 2.0\boldsymbol{a}_y + 0.6\boldsymbol{a}_z)$ volt/m

MCQ 3.4.3 The electric field on the surface of a perfect conductor is 2 V/m. The conductor is immersed in water with $\varepsilon = 80\varepsilon_o$. The surface charge density on the conductor is ($\varepsilon = \frac{10^{-9}}{36\pi}$ F/m)
(A) 0 C/m²
(B) 2 C/m²
(C) 1.8×10^{-11} C/m²
(D) 1.41×10^{-9} C/m²

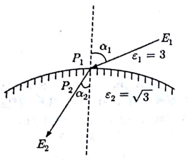
MCQ 3.4.4 The space between the plates of a parallel-plate capacitor of capacitance C is filled with three dielectric slabs of identical size as shown in the figure. If dielectric constants are ε_1, ε_2 and ε_3, the new capacitance is



(A) $\frac{C}{3}$ (B) $\frac{(\varepsilon_1 + \varepsilon_2 + \varepsilon_3)C}{3}$
(C) $(\varepsilon_1 + \varepsilon_2 + \varepsilon_3)C$ (D) $\frac{9(\varepsilon_1 + \varepsilon_2 + \varepsilon_3)}{\varepsilon_1 \varepsilon_2 \varepsilon_3}$

MCQ 3.4.5 If the potential, $V = 4x + 2$ V, the electric field is
(A) 6 V/m (B) 2 V/m
(C) 4 V/m (D) $-4\boldsymbol{a}_x$ V/m

MCQ 3.4.6 Two dielectric media with permittivities 3 and $\sqrt{3}$ are separated by a charge-free boundary as shown in figure below :



The electric field intensity in media 1 at point P_1 has magnitude E_1 and makes an angle $\alpha_1 = 60°$ with the normal. The direction of the electric field intensity at point P_2, α_2 is

(A) $\sin^{-1}\left(\frac{\sqrt{3}\,E_1}{2}\right)$ (B) $45°$

(C) $\cos^{-1}\left(\frac{\sqrt{3}\,E_1}{2}\right)$ (D) $30°$

MCQ 3.4.7 **Assertion (A) :** Under static conditions, the surface of conductor is an equipotential surface.

Reason (R) : The tangential component of electric field on conductor surface is zero.

(A) Both **Assertion (A)** and **Reason (R)** are individually true and **Reason (R)** is the correct explanation of **Assertion (A)**

(B) Both **Assertion (A)** and **Reason (R)** are individually true but **Reason (R)** is not the correct explanation of **Assertion (A)**

(C) **Assertion (A)** is true but **Reason (R)** is false

(D) **Assertion (A)** is false but **Reason (R)** is true

MCQ 3.4.8 A long 1 metre thick dielectric ($\varepsilon = 3\varepsilon_0$) slab occupying the region $0 < x < 5$ is placed perpendicularly in a uniform electric field $\boldsymbol{E}_0 = 6\boldsymbol{a}_x$. The polarization $\boldsymbol{P}_i$ inside the dielectric is

(A) $4\varepsilon_0\,\boldsymbol{a}_x$ (B) $8\varepsilon_0\,\boldsymbol{a}_x$

(C) $36\varepsilon_0\,\boldsymbol{a}_x$ (D) Zero

MCQ 3.4.9 The flux and potential functions due to a line charge and due to two concentric circular conductors are of the following form :

(A) Concentric circular equipotential lines and straight radial flux lines.

(B) Concentric circular flux lines and straight equipotential lines

(C) Equipotentials due to the charge are concentric cylinders and equipotentials due to two conductors are straight lines.

(D) Equipotentials due to line charge are straight flat surfaces and those due to two conductors are concentric cylinders.

MCQ 3.4.10 There are two conducting plates of sizes $1\text{ m} \times 1\text{ m}$ and $2\text{ m} \times 2\text{ m}$. Ratio of the capacitance of the second one with respect to that of the first one is

(A) 4 (B) 2

(C) 1/2 (D) 1/4

MCQ 3.4.11 Consider the following :

In a parallel plate capacitor, let the charge be held constant while the dielectric material is replaced by a different dielectric. Consider

1. Stored energy 2. Electric field intensity.
3. Capacitance

Which of these changes ?

(A) 1 only (B) 1 and 2 only

(C) 2 and 3 only (D) 1, 2 and 3

MCQ 3.4.12 By what name is the equation $\nabla \cdot \boldsymbol{J} = 0$ frequently known ?

(A) Poisson's equation

(B) Laplace's equation

(C) Continuity equation for steady currents

(D) Displacement equation

MCQ 3.4.13 Method of images is applicable to which fields ?

(A) Electrostatic fields only

(B) Electrodynamic fields only

(C) Neither electrostatic fields nor electrodynamic fields

(D) Both electrostatic fields and electrodynamic fields

MCQ 3.4.14 What is the unit of measurement of surface or sheet resistivity?

(A) Ohm/metre (B) Ohm metre

(C) Ohm/sq. meter (D) Ohm

MCQ 3.4.15 Which one of the following statements is correct ?

On a conducting surface boundary, electric field lines are

(A) always tangential

(B) always normal

(C) neither tangential nor normal

(D) at an angle depending on the field intensity

MCQ 3.4.16 Which one of the following is correct ? As frequency increases, the surface resistance of a metal

(A) decreases

(B) increases

(C) remains unchanged

(D) varies in an unpredictable manner

MCQ 3.4.17 Application of the method of images to a boundary value problem in electrostatics involves which one of the following ?

(A) Introduction of an additional distribution of charges and removal of a set of conducting surfaces

(B) Introduction of an additional distribution of charge and an additional set of conducting surfaces

(C) Removal of a charge distribution and introduction of an additional set of conducting surfaces

(D) Removal of a charge distribution as well as a set of conducting surfaces

MCQ 3.4.18 **Assertion (A) :** Potential everywhere on a conducting surface of infinite extent is zero.
Reason (R) : Displacement density on a conducting surface is normal to the surface.
(A) Both A and R are true and R is the correct explanation of A
(B) Both A and R are true but R is NOT the correct explanation of A
(C) A is true but R is false
(D) A is false but R is true

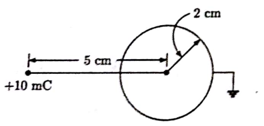
MCQ 3.4.19 A parallel plate capacitor of 5 pF capacitor has a charge of 0.1 μC on its plates. What is the energy stored in the capacitor ?
(A) 1 mJ (B) 1 μJ
(C) 1 nJ (D) 1 pJ

MCQ 3.4.20 A charge of 1 Coulomb is placed near a grounded conducting plate at a distance of 1 m. What is the force between them ?
(A) $\frac{1}{4\pi\varepsilon_0}$ N (B) $\frac{1}{8\pi\varepsilon_0}$ N
(C) $\frac{1}{16\pi\varepsilon_0}$ N (D) $4\pi\varepsilon_0$ N

MCQ 3.4.21 The capacitance of a parallel plate capacitor is given by $\frac{\varepsilon_r\varepsilon_0 A}{d}$ where A is the area of each plates. Considering fringing field, under which one of the following conditions is the above expression valid ?
(A) $\frac{A}{d}$ is tending towards zero (B) $\frac{A}{d}$ is tending towards infinity
(C) $\frac{A}{d}$ is 1 (D) $\frac{A}{d}$ is $\frac{1}{\varepsilon_r\varepsilon_0}$

MCQ 3.4.22 What is the expression for capacitance of a solid infinitely conducting solid sphere of radius 'R' in free space ?
(A) $2\pi\varepsilon_0 R$ (B) $4\pi\varepsilon_0 R$
(C) $8\pi\varepsilon_0 R$ (D) $0.5\pi\varepsilon_0 R$

MCQ 3.4.23 A point charge of +10 μC placed at a distance of 5 cm from the centre of a conducting grounded sphere of radius 2 cm is shown in the diagram given below :



What is the total induced charge on the conducting sphere ?
(A) 10 μC (B) 4 μC
(C) 5 μC (D) 12.5 μC

MCQ 3.4.24 For an electric field $E = E_0 \sin\omega t$, what is the phase difference between the conduction current and the displacement current ?
(A) 0° (B) 45°
(C) 90° (D) 180°

MCQ 3.4.25 An infinitely long line charge of uniform charge density ρ_l C/m is situated parallel to and at a distance from the grounded infinite plane conductor. This field problem can be solved by which one of the following ?
(A) By conformal transformation
(B) By method of images
(C) By Laplace's equation
(D) By Poisson's equation

MCQ 3.4.26 An air condenser of capacitance of 0.005 μF is connected to a d.c. supply of 500 Volts, disconnected and then immersed in oil with a dielectric constant of 2.5. Energy stored in the capacitor before and after immersion, respectively is
(A) 500×10^{-4} J and 250×10^{-4} J
(B) 250×10^{-4} J and 500×10^{-4} J
(C) 625×10^{-4} J and 250×10^{-4} J
(D) 250×10^{-4} J and 625×10^{-4} J

MCQ 3.4.27 A 3 μF capacitor is charged by a constant current of 2 μA for 6 seconds. The voltage across the capacitor to the end of charging will be
(A) 3 V (B) 4 V
(C) 6 V (D) 9 V

MCQ 3.4.28 Consider the following statements :
A parallel plane capacitor is filled with a dielectric of relative permittivity ε_{r1} and connected to a d.c. voltage of V volts. If the dielectric is changed to another with relative permittivity $\varepsilon_{r2} = 2\varepsilon_{r1}$, keeping the voltage constant, then
1. the electric field intensity $\boldsymbol{E}$ within the capacitor doubles.
2. the displacement flux density $\boldsymbol{D}$ doubles
3. the charge Q on the plates is reduced to half.
4. the energy stored in the capacitor is doubled.

Select the correct answer using the codes given below :
(A) 1 and 2
(B) 2 and 3
(C) 2 and 4
(D) 3 and 4

MCQ 3.4.29 A coil of resistance 5 Ω and inductance 0.4 H is connected to a 50 V d.c. supply. The energy stored in the field is
(A) 10 joules (B) 20 joules
(C) 40 joules (D) 80 joules

MCQ 3.4.30 The normal components of electric flux density across a dielectric-dielectric boundary
(A) are discontinuous
(B) are continuous
(C) depend on the magnitude of the surface charge density
(D) depend on electric field intensity

MCQ 3.4.31 Consider the following statements in connection with boundary relations of electric field :

1. In a single medium electric field is continuous.
2. The tangential components are the same on both sides of a boundary between two dielectrics.
3. The tangential electric field at the boundary of a dielectric and a current carrying conductors with finite conductivity is zero.
4. Normal components of the flux density is continuous across the charge-free boundary between two dielectrics.

Which of these statements is/are correct ?

(A) 1 only (B) 1, 2 and 3

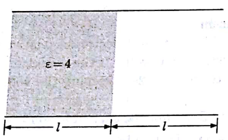
(C) 1, 2 and 4 (D) 3 and 4 only

MCQ 3.4.32 The capacitance of an insulated conducting sphere of radius R in vacuum is

(A) $2\pi\varepsilon_0 R$ (B) $4\pi\varepsilon_0 R$

(C) $4\pi\varepsilon_0 R^2$ (D) $4\pi\varepsilon_0/R$

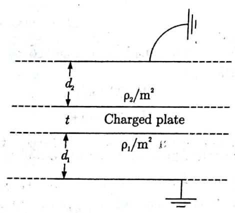
MCQ 3.4.33 A parallel plate air capacitor carries a charge Q at its maximum withstand voltage V. If the capacitor is half filled with an insulating slab of dielectric constant 4 as shown in the figure given below, what are the maximum withstand voltage and the charge on the capacitor at this voltage, respectively ?



(A) $2.5\,V,\,Q$ (B) $4\,V, 2.5\,Q$

(C) $V, 2.5\,Q$ (D) $V/4, Q$

MCQ 3.4.34 When an infinite charged conducting plate is placed between two infinite conducting grounded surfaces as shown in the figure given below, what would be the ratio of the surface densities ρ_1 and ρ_2 on the two sides of the plate ?



(A) $\frac{(d_1+t)}{(d_2+t)}$ (B) $\frac{(d_2+t)}{(d_1+t)}$

(C) $\frac{d_1}{d_2}$ (D) $\frac{d_2}{d_1}$

MCQ 3.4.35 The polarization in a solid dielectric is related to the electric field $\boldsymbol{E}$ and the electric flux density $\boldsymbol{D}$ according to which on of the following equations ?

(A) $\boldsymbol{E} = \varepsilon_0 \boldsymbol{D} + \boldsymbol{P}$

(B) $\boldsymbol{D} = \varepsilon_0(\boldsymbol{E} + \boldsymbol{P})$

(C) $\boldsymbol{D} = \varepsilon_0 \boldsymbol{E} + \boldsymbol{P}$

(D) $\boldsymbol{E} = \boldsymbol{D} + \varepsilon_0 \boldsymbol{P}$

MCQ 3.4.36 Image theory is applicable to problems involving

(A) electrostatic field only

(B) magnetostatic field only

(C) both electrostatic and magnetostatic fields

(D) neither electrostatic nor magnetostatic field

MCQ 3.4.37 Six capacitors of different capacitances C_1, C_2, C_3, C_4, C_5 and C_6 are connected in series. $C_1 > C_2 > C_3 > C_4 > C_5 > C_6$. What is the total capacitance almost equal to ?

(A) C_1 (B) C_3

(C) C_4 (D) C_6

MCQ 3.4.38 Two extensive homogeneous isotropic dielectrics meet on a plane $z = 0$. For $z \geq 0$, $\varepsilon_{r1} = 4$ and for $z \leq 0$, $\varepsilon_{r2} = 2$. A uniform electric field exists at $z \geq 0$ as $\boldsymbol{E}_1 = 5\boldsymbol{a}_x - 2\boldsymbol{a}_y + 3\boldsymbol{a}_z$ kw/m. What is the value of $\boldsymbol{E}_{2z}$ in the region $z \leq 0$?

(A) $3\boldsymbol{a}_z$

(B) $5\boldsymbol{a}_x - 2\boldsymbol{a}_y$

(C) $6\boldsymbol{a}_z$

(D) $\boldsymbol{a}_x - \boldsymbol{a}_y$

MCQ 3.4.39 A flat slab of dielectric, $\varepsilon_r = 5$ is placed normal to a uniform field with a flux density $D = 1$ Coulomb/m². The slab is uniformly polarized. What is the polarization P of the slab in Coulomb/m² ?

(A) 0.8 (B) 1.2

(C) 4 (D) 6

MCQ 3.4.40 Which one of the following gives the approximate value of the capacitance between two spheres, whose separation is very much larger than their radii R ?

(A) $2\pi/\varepsilon_0 R$ (B) $2\pi\varepsilon_0 R$

(C) $2\pi\varepsilon_0/R$ (D) $4\pi\varepsilon_0/R$

MCQ 3.4.41 **Assertion (A) :** For steady current in an arbitrary conductor, the current density is solenoidal

Reason (R) : The reciprocal of the resistance is the conductivity.

(A) Both A and R are true and R is the correct explanation of A

(B) Both A and R are true but R is NOT the correct explanation of A

(C) A is true but R is false

(D) A is false but R is true

MCQ 3.4.42 **Assertion (A) :** Displacement current can have only a.c components.
Reason (R) : It is generated by a change in electric flux.
(A) Both A and R are true and R is the correct explanation of A
(B) Both A and R are true but R is NOT the correct explanation of A
(C) A is true but R is false
(D) A is false but R is true

MCQ 3.4.43 A plane slab of dielectric having dielectric constant 5, placed normal to a uniform field with a flux density of 2 C/m^2, is uniformly polarized. The polarization of the slab is
(A) 0.4 C/m^2
(B) 1.6 C/m^2
(C) 2.0 C/m^2
(D) 6.4 C/m^2

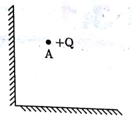
MCQ 3.4.44 Ohm's law in point form in the field theory can be expressed as
(A) $V = RI$
(B) $J = E/\sigma$
(C) $J = \sigma E$
(D) $R = \rho l/A$

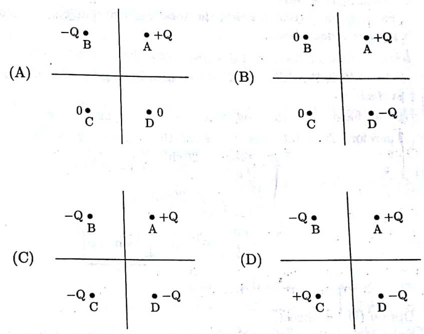
MCQ 3.4.45 A medium behaves like dielectric when the
(A) displacement current is just equal to the conduction current
(B) displacement current is less than the conduction current
(C) displacement current is much greater than the conduction current
(D) displacement current is almost negligible

MCQ 3.4.46 A copper wire carries a conduction current of 1.0 A at 50 Hz. For copper wire $\varepsilon = \varepsilon_0$, $\mu = \mu_0$, $\sigma = 5.8 \times 10$ mho/m. What is the displacement current in the wire ?
(A) 2.8×10 A
(B) 4.8×10^{-11} A
(C) 1 A
(D) It cannot be calculated with the given data

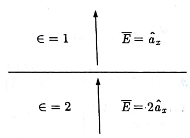
MCQ 3.4.47 **Assertion (A) :** When there is no charge in the interior of a conductor the electric field intensity is infinite.
Reason (R) : As per Gauss's law the total outward electric flux through any closed surface constituted inside the conductor must vanish.
(A) Both A and R are true and R is the correct explanation of A
(B) Both A and R are true but R is NOT the correct explanation of A
(C) A is true but R is false
(D) A is false but R is true

MCQ 3.4.48 A point charge $+Q$ is brought near a corner of two right angle conducting planes which are at zero potential as shown in the given figure. Which one of the following configurations describes the total effect of the charges for calculating the actual field in the first quadrant ?





MCQ 3.4.49 The electric field across a dielectric-air interface is shown in the given figure. The surface charge density on the interface is



(A) $-4\varepsilon_0$
(B) $-3\varepsilon_0$
(C) $-2\varepsilon_0$
(D) $-\varepsilon_0$

MCQ 3.4.50 When air pocket is trapped inside a dielectric of relative permittivity '5', for a given applied voltage across the dielectric, the ratio of stress in the air pocket to that in the dielectric is equal to
(A) 1/5
(B) 5
(C) $1+5$
(D) $5-1$

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